Simulation and Design of SRF based Control Algorithm for Three Phase Shunt Active Power Filter

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***Abstract*— Active power filters are effective in mitigating line current harmonics and compensating for the reactive power in the line. There are basically two types of Active Power Filters (APFs): shunt type and series type. Shunt active power filters (SAPFs) represent the most important and most widely used filters in industrial purposes, this is due not only to the fact that eliminate the harmonic current but also they are suitable for a wide range of power ratings. In this paper, Synchronous Reference Frame (SRF) theory is employed to calculate compensating currents while the three phase source is feeding a highly non-linear load. The main objective is to study and investigate the performance of Shunt active power filter using SRF theory. The algorithm is simulated under MATLAB 7.8 environment using Simulink** and **SimPowerSystems toolbox. The results shown are within the IEEE Standard 512-1992.**

***Index Terms*— Power Quality, Shunt Active Power Filter, Synchronous Reference Frame, Harmonic mitigation**

I. INTRODUCTION

The advancement in semiconductor device technology made a revolution in power electronics over the past decade. Thus, power electronic related equipment's have been widely used in various areas. However, power electronic based equipment's which includes adjustable speed motor drives, electronic power supplies, DC motor drives, battery chargers, electronic ballasts are responsible for the rise in power quality related issues[1]. These nonlinear loads appear to be prime sources of harmonic distortion in a power distribution system. Harmonics have a number of undesirable effects on the distribution system. The simplest solution to mitigate the harmonic distortion is passive filtering. Although simple, it do not always respond correctly to the dynamics of the distribution systems due to the drawbacks like electromagnetic interference, possible resonance, fixed compensation, bulkiness, etc. which affects the stability of the power distribution systems. To cope with these disadvantages, active power filters came into views around 1970's.The concept of APF was proposed by H.Sasaki and T.Machida in [2]. In 1982, an active power filter of 800kVA, which consisted of current source PWM inverters using GTO thyristors, was put into practical use for harmonic compensation for the first time in the world. Figure 1 shows the APF Configuration with VSI.

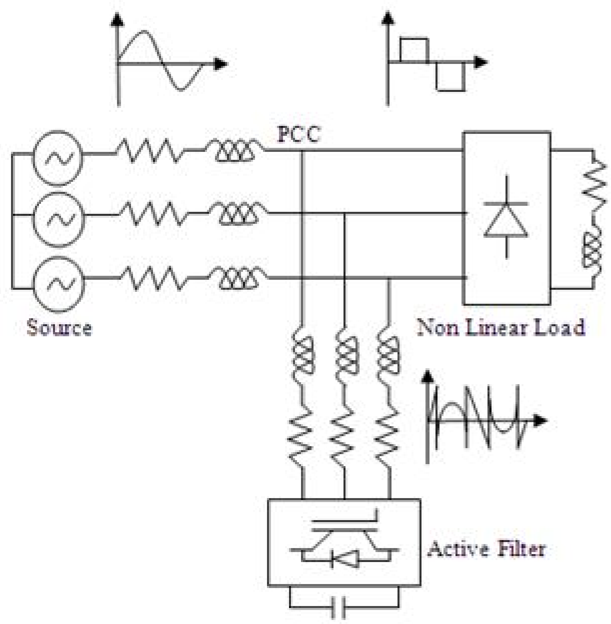

Figure 1. APF configuration with VSI

II. SHUNT ACTIVE POWER FILTER

There are several types of active filter topologies used to compensate the harmonics as well as reactive power [3], [4], [5]. The shunt active power filter is one of the configurations of the APFs, which is widely used for its better performance.

VSI along with capacitor is used to generate the compensating current (i_c) and the compensating current is injected into grid by connecting the filter in parallel. So the compensation is achieved by cancelling the harmonics produced by non-linear loads.

The performance of SAPF is based on three design criteria:

- Extraction method: This extracts harmonic current from load current which is considered as compensating currents to be injected by the APF.
- Current source: Three- phase VSI, controlled as a current source, used to inject the compensating currents into the power system.
- Switching technique: It includes current control

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algorithm to drive the inverter using different types of modulating techniques.

There are several extraction techniques like, Instantaneous reactive power theory, Instantaneous power theory based on symmetrical components, Generalized Instantaneous reactive power theory, Synchronous reference frame theory (SRF), Synchronous Detection Method (SDM), etc. In this paper, SRF theory is used to generate the reference signals applied to current control algorithm.

III. Synchronous Reference Frame Theory Based Compensation

Three phase load currents have taken as input for extraction algorithm. Figure 2 depicts the extraction algorithm used in MATLAB/Simulink.

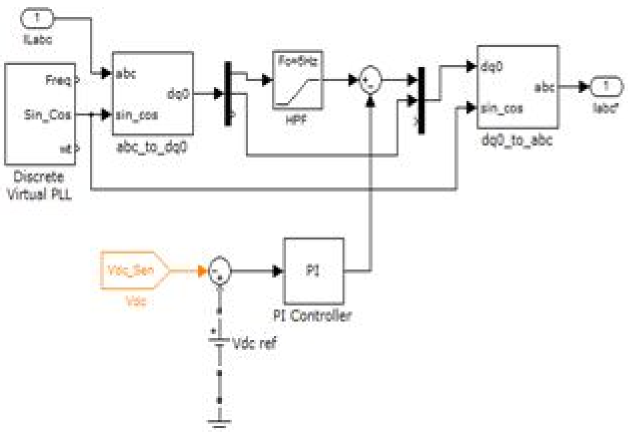

Figure 2. MATLAB/Simulink model of SRF Based Extraction algorithm

Park's Transformation and Clarke's Transformation are used to decouple the active and reactive components. Park's Transformation is used to simplify the computational complexity by converting the three phase components into equivalent two phase components. Equations 1 and 2 shows the Clarke and Park Transformers applied to phasors [5], [7].

$$\begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} = \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} I_d \\ I_q \end{bmatrix} = \begin{bmatrix} \cos\omega t & \sin\omega t \\ -\sin\omega t & \cos\omega t \end{bmatrix} \begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} \quad (2)$$

The equations to explain these load current on dq frame are

$$\begin{bmatrix} I_{Ld} \\ I_{Lq} \end{bmatrix} = \begin{bmatrix} \bar{I}_{Ld} + \tilde{I}_{Ld} \\ \bar{I}_{Lq} + \tilde{I}_{Lq} \end{bmatrix} \quad (3)$$

When $\bar{I}_{Ld}, \bar{I}_{Lq}$ and $\tilde{I}_{Ld}, \tilde{I}_{Lq}$ are the DC components and AC component of the load currents on dq- frame, respectively. From equation (3), it is shown that the dq load currents consist of two terms. The high-pass filter (HPF) is used to separate the harmonic components $\tilde{I}_{Ld}$ $\tilde{I}_{Lq}$ from the dq load currents (i_{Ld}, i_{Lq}) as shown in Fig.3. Half of the fundamental frequency is taken as the cut-off frequency of the high pass filter.

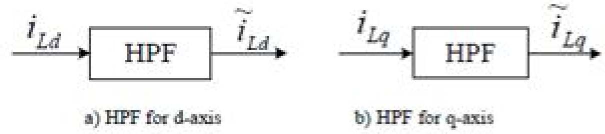

Figure 3. Seperation of Harmonic Components

Finally, the harmonic components are converted back into three phase quantities by applying Reverse Park's and Reverse Clarke's Transformations as shown in equations 4 and 5. These signals are taken as reference signals to the hysteresis current controller to generate the gate pulses to the Inverter.

$$\begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} = \begin{bmatrix} \cos\omega t & -\sin\omega t \\ \sin\omega t & \cos\omega t \end{bmatrix} \begin{bmatrix} I_d \\ I_q \end{bmatrix} \quad (4)$$

$$\begin{bmatrix} I_a^* \\ I_b^* \\ I_c^* \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} \quad (5)$$

Here, PI controller is used whose output is added with the d-axis harmonics reference to generate the total d-axis current reference for the current controller. PI controller output is based on capacitor voltage and reference voltage (V_{dc}).

IV. Hysteresis Current Controller

Hysteresis current control technique is employed to design the control part of the APF. The compensating current control using the hysteresis approach is shown in Figure 4. Hysteresis band (HB) is used as the boundary of compensating current (i_c). This current is controlled between upper and lower hysteresis limits [6]. The compensating current can be increased or decreased depending on the pattern switch of inverter inside the APF. When IGBT turns on, i_c will be increased. It is continually increased until reaching the upper hysteresis limit.

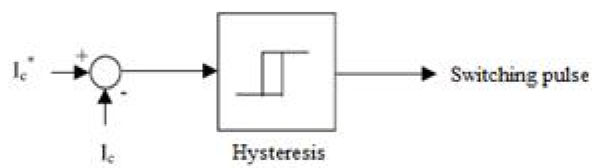

Figure 4. Hysteresis Current Controller

At this state, IGBT will be automatically turned off to decrease the compensating current. If the current falls down to the lower limit, inverter will be automatically turned on again to increase the compensating current. Therefore, the compensating current swings inside HB following the reference current i_c*. The reference current can be identified by SRF harmonic detection. Note that the upper and lower limits of hysteresis are controlled by the hysteresis band. Figure 5 depicts operating principle of hysteresis current controller.

Figure 6. shows hysteresis current control block used in MATLAB/Simulink.

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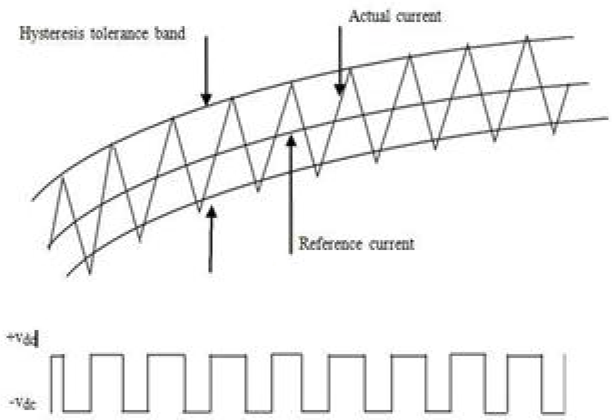

Figure 5. Hysteresis Current Control Operation

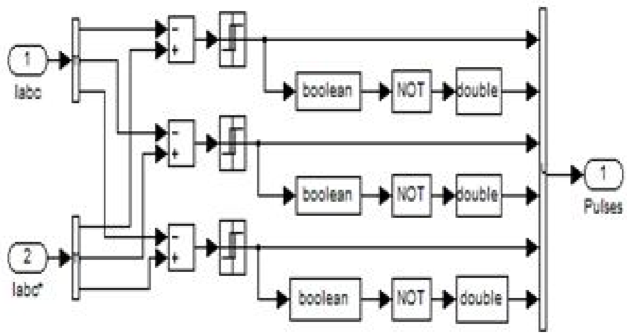

Figure 6. MATLAB/Simulink Model of Hysteresis Current Controller

V. Simulation Results

The Shunt Active Power Filter system based on Synchronous Reference Frame Theory has been successfully modelled and simulated using MATLAB/ SIMULINK power system toolbox software. The load is taken as a three phase diode bridge rectifier feeding resistive load of 6.7 Ω with the line inductance of 20mH. Figure 7 shows harmonic spectrum of system before compensation applied.

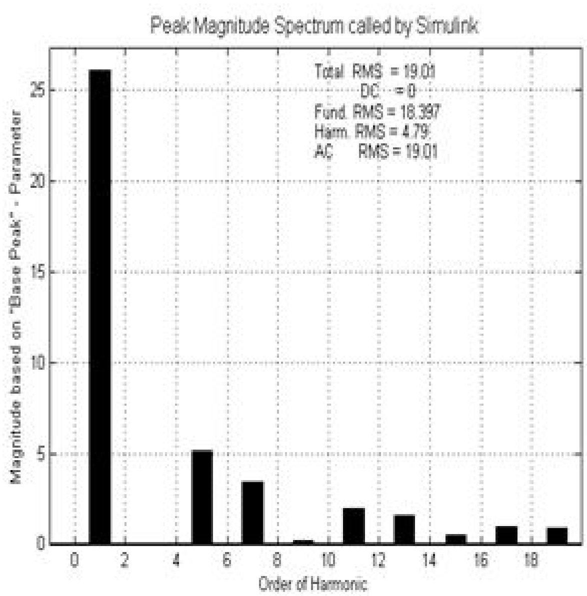

Figure 7. Harmonic Spectrum before Compensation

Waveforms of source voltage, source current and load current before compensation are shown in Figure 8. THD of Source current before compensation is 27.28 %. Nature of source current is polluted by harmonics produced by non-linear load. So source and load current waveform shapes are similar before compensation

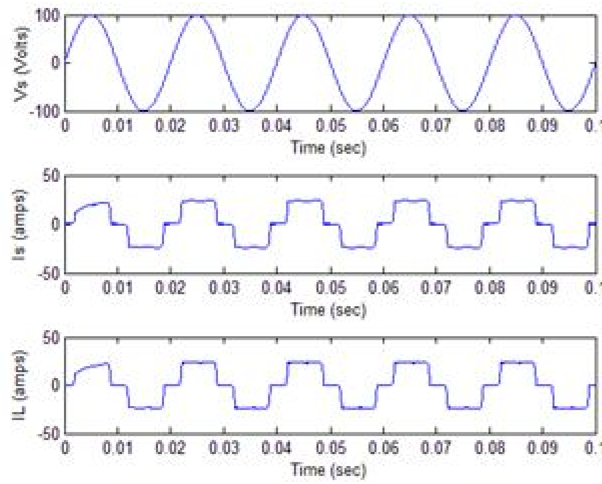

Figure 8. Waveforms of Three Phase System before Compensation

Spectrum of Source current after compensation is shown in Figure 9.

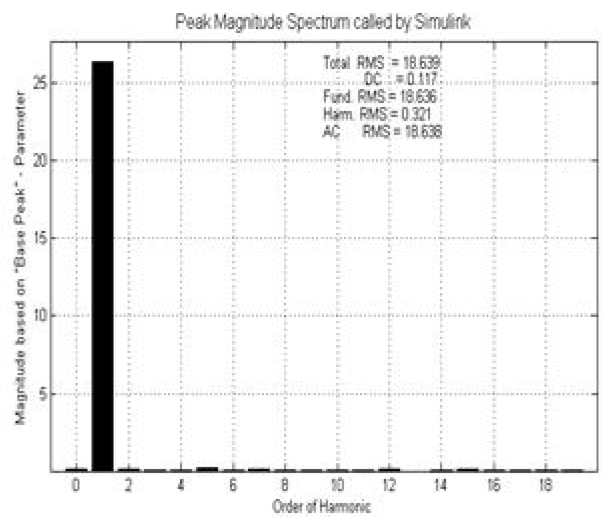

Figure 9. Harmonic Spectrum of System after Compensation

The performance of the proposed approach for the regulation of APF is analysed and the waveforms shows the response of the filter after compensation is applied. The total harmonic distortion (THD) in the source current is reduced to 2.58 %.

Figure 10. depicts the waveforms of line current after SAPF connected at PCC.

Conclusions

In this paper SRF theory is applied to the shunt active power filter to compensate reactive and harmonic currents under balanced source voltage conditions. This method compensates the source current and the THD is evidently

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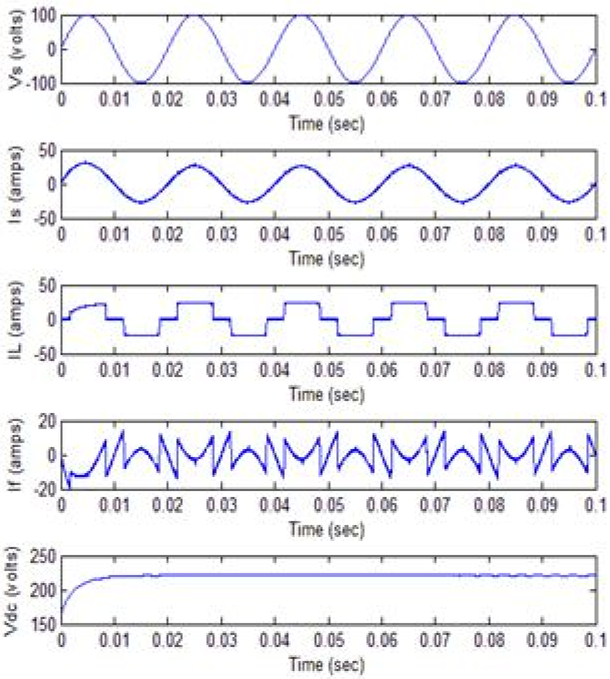

Figure 10. Response of I_d-I_q Extraction Based Shunt Active Power Filter

reduced which is within the IEEE standards. It is found that the technique works satisfactorily yielding a sinusoidal source current and the performance of SAPF using SRF theory is tested through Simulink. In future, the current work would be improved by the application of soft computing techniques and validated through hardware implementation.

Appendix

Design Specification And Parameters

The system parameters are given here;

Source Voltage (V_s): 100 V
Source Resistance (R_s): 0.1 Ω
Source Inductance (L_s): 0.15 mH
Load Resistance (RL): 20Ω
Load Inductance (LL): 0.67 mH
Filter Resistance (R_f): 0.1Ω
Filter Inductance (L_f): 0.66 mH
Reference DC Link Voltage (V_{dc}): 220 V
DC Capacitance (C_{dc}): 2000 μF

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